POLARIZATION OF EXCITED NUCLEAR LEVELS INDUCED BY ATOMIC ORIENTATION *

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The effect of atomic orientation produced in a tilted-foil geometry on the angular correlation of nuclear decay γ-rays is investigated. A quantum mechanical treatment is presented for the case of a known electronic ensemble. An approximate phenomenological approach is suggested for heavy ions recoiling out of the target with a multi-electron complex environment. The utilization of this approach in hyperfine interaction experiments is discussed.

1. Introduction

Studies of hyperfine interaction (HFI) utilizing perturbed angular distribution of γ-rays from nuclear decay have been extensively used to obtain information on both nuclear and atomic systems. Quantum mechanical treatments of the effect of atomic fields on the angular distribution considered mainly aligned systems (with no orientation) [1]. Recently, however, interest has arisen in systems in which the atomic fields are polarized. Such polarization can be obtained if the excited nuclei recoil out of a foil whose surface is not perpendicular to the beam direction [2,3], or recoil into a magnetized material [4]. The polarized atomic fields are commonly treated as classical external magnetic fields leading to a simple precession of the angular distribution. Goldring [5] has shown that the quantum mechanical expression for the effect in the limit of small precessions indeed converges to the classical limit. In practice this is the case for measurements of recoil into a magnetic material (transient field experiments). For recoil into vacuum (tilted-foil experiments), the classical approximation may not hold. Even a small measured left-right asymmetry of the angular distribution can be the result of averaging large precessions over the electronic ensemble [3] or the result of a large field which is only slightly polarized. In the following we extend the quantum mechanical treatment to the case where the pre-

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cession angles are large. We also present a procedure for evaluating precession experiments involving complex electronic ensembles. With the relations derived below, experiments concerning nuclear states with a large range of lifetimes and magnetic moments can be interpreted in a consistent way.

The effect of a static atomic polarization on the angular distribution $W(\theta, \phi, t)$ of nuclear decay $\gamma$-rays is manifested in the time dependence of the nuclear density tensors $\rho_{kN}^{qN}$, which appear in the expression:

$$W(\theta, \phi, t) = \sum_{kN,qN} U_{kN} \rho_{kN}^{qN}(I, t) Y_{kN}^{qN}(\theta, \phi),$$

with $U_{kN}$ depending on the particulars of the nuclear excitation and de-excitation.

We consider two cases: of a single atomic state, and of an ensemble of atomic states.

2. The case of a single atomic state

Consider an ion in a pure $(L, S, J)$ state with a certain fractional polarization $p = \langle L_z \rangle / \sqrt{L(L+1)}$ at $t = 0$. This polarization is related to the atomic density tensor in the following way:

$$p = \rho_{1}^{0}(L) \sqrt{3(2L + 1)}.$$  

We assume for simplicity that $\rho_{1}^{0}$ is the only non-trivial component at $t = 0$. The conventional choice of the z-axis is taken to be along the beam direction, therefore we define the direction of polarization as the x-axis so that $p = \langle L_z \rangle / \sqrt{L(L+1)}$ (fig. 1).

Applying the relevant rotation to $\rho_{1}^{0}$ in the above relation, and transforming the atomic density tensor to the $J$ representation we obtain:

$$\rho_{k=1}^{q=\pm 1}(J, t = 0) = \mp \rho_{k}^{0}(J) \cos(J, L) p \sqrt{3} / 2, \quad (L \neq 0),$$  

![Fig. 1. The coordinate system for a typical hyperfine interaction tilted-foil experiment (see refs. [2,3]). $\psi$ is the angle between the normal $\hat{n}$ and the beam direction. The electronic polarization is in the $+x$ direction. $\gamma$-counters to measure the angular distribution are positioned in the $\hat{y} - \hat{z}$ plane.](image-url)